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by

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Consumer needs and their satiation properties as drivers of the rebound effect

The case of energy-efficient washing machines

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Abstract: The possibility of the "rebound effect" to technological progress has triggered a debate in energy economics concerning the usefulness of the promotion of efficiency progress. Until now, a multitude of empirical evidence has been gathered so to assess the magnitude of the effect in the first place. Progress in theoretical research has been rather modest, however. In this paper, we argue for a broadening of the theoretical basis beyond neoclassical consumer theory. We more specifically suggest turning toward consumption theories that deal with consumer needs and learning processes. We postulate that the rebound effect to energy efficiency progress is a special case of behavioral reactions to technological change more in general. Our central hypothesis is that rebound effects will only occur as long as the consumer needs appealed to by the product are not yet satiated. We exemplarily illustrate how to apply these arguments for the case of energy-efficient washing machines.

Keywords: rebound effect, consumer needs, washing machines.

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1. Problem statement

Current sustainability policies and legislation show a strong emphasis on efficiency progress in energy-using consumer products, i.e., product differentiation along the characteristics of environment-friendliness. However, efficiency improvements in products such as household appliances need not lead to a one-to-one reduction in residential energy use. “Rebound effects”, i.e., energy savings partly being offset through the more intensive use of certain goods (Khazzoom, 1980), have been observed, for example, in the context of fuel-efficient cars (e.g., de Haan et al., 2006; Greene, 1992; Greening et al., 2000).

The possibility of the rebound effect has triggered a debate in energy economics concerning the usefulness of the promotion of energy-efficiency progress. The fact that rebound effects have primarily been treated as an empirical question – so to assess the magnitude of the problem in the first place – is therefore not surprising. A couple of studies have estimated these effects for different types of products and/or activities and levels of aggregation (e.g., Greening et al., 2000; Polimeni and Polimeni, 2006). In most cases, direct effects have been estimated to be rather moderate, including the single study of washing machines we know of (Davis, 2008).

In contrast to that, progress in theoretical research has been rather modest. The neoclassical model of consumer behavior, particularly the price elasticity of demand, is the theoretical frame of reference for micro-level analyses (e.g., Berkhout et al., 2000). Although utilization patterns of more efficient domestic appliances are likely to reflect consumer price-sensitivity to a certain extent, we posit that focusing on relative prices alone, i.e., decreasing product utilization costs, is too limited a perspective.

In fact, we view the rebound effect to efficiency progress as a special case of behavioral reactions to technological change more in general, which are contingent on yet unsatisfied consumer needs with regard to that consumption activity. Otherwise, behavioral reactions to technological progress will reach a boundary. In this paper, we argue for a broadening of the theoretical basis of rebound analysis by turning toward consumption theories which deal with consumer needs and learning processes. The theoretical underpinning of our analysis is the “theory of learning consumers” by Witt (2001).

Our reasoning along these lines suggests a case study specific approach in the form of a detailed analysis of adoption and utilization patterns for a specific household appliance. We choose washing machines as an example and study changes in their utilization patterns with regard to

consumer needs and their satiation properties. Washing machines are an interesting case for several reasons: firstly, their energy-efficiency has improved significantly in the past years; secondly, they serve several consumer needs; and thirdly, they are an example for continuous technological progress throughout the 20th century having coincided with a growth in laundry amounts (Ruedenauer and Griesshammer, 2004; Shove, 2003b). Hence, the occurrence of rebound effects as a consequence of further efficiency improvements in clothes washers is a plausible scenario. However, based on the framework of driving forces considered here, we argue that rebound effects are not likely to occur in the future.

Our research makes the following contributions. Firstly, we integrate the concepts of consumer needs and their satiation properties into the body of literature on rebound effects. Secondly, we tackle a rather novel case study by analyzing washing machines; scholarly attention has usually been directed toward studying rebound effects with transportation.

This paper contains six sections. The theoretical background of and empirical evidence on rebound effects are presented in more detail in section 2. Therein, we also identify the research gap in the literature, i.e., the neglect of saturation effects in demand. In section 3, we introduce the theory of learning consumers by Witt (2001) as well as the core hypotheses of this analysis. We show how the concepts of consumer needs and their satiation properties can be integrated into an analysis of the rebound effect. Section 4 provides background information on the case study, including a depiction of the market for washing machines and a discussion of the phenomenon of rising laundry quantities in the past. Furthermore, the motivations involved in clothes washing will be identified. Section 5 studies the satiation properties of the needs associated with laundry washing and explains why the future occurrence of rebound effects is rather unlikely. Section 6 concludes.

2. Rebound effects

2.1 Theory

In this section, we describe how rebound effects have been analyzed from the perspective of neoclassical consumer theory, which is the conventional approach in the literature, and which questions are left open in that account. In most general terms, rebound effects can be defined as the consumption of a resource (e.g., fuel) or the use of a technology in response to technological progress, namely efficiency improvements. More precisely, the term rebound describes the case

that energy savings as predicted by engineering analysis do not materialize as energy-efficiency improvements are accompanied by a more intensive use of fuel as such or the respective technology, in which it is employed (e.g., Brookes, 1978; Khazzoom, 1980; Khazzoom, 1987). In short, rebound describes the discrepancy between potential and actual energy savings, which stems from behavioral reactions in contrast to keeping the status quo. It is usually measured as a percentage of the savings predicted by engineering (Madlener and Alcott, 2009, p.370).

Different types of rebound effects are distinguished, depending on the scope of research, namely micro- or macro-level analyses (see, e.g., Herring and Roy, 2007).[2] "Direct" and "indirect" rebound effects are micro-level phenomena (e.g., Madlener and Alcott, 2009), which have been discussed in the context of production processes (Birol and Keppler, 2000) and consumption behavior (Berkhout et al., 2000). Direct effects concern one consumption activity, such as laundry washing, in isolation. Indirect effects denote growth in the use of energy services in other consumption contexts, hence changes in the demand for other goods. To study indirect effects, more than one consumption act has to be taken into account. Whether indirect and economy-wide effects occur depends on the relative resource intensity of the respective consumption activities and the direction of change (Berkhout et al., 2000).[3] This study is confined to direct micro-level effects in household behavior.

The engineering definition of the direct rebound effect is an efficiency elasticity of demand, whereas the economic literature usually conceptualizes it as a *price elasticity of demand* (Sorrel and Dimitropoulos, 2008). Let us consider the economic interpretation. Two kinds of price elasticities of demand have to be distinguished: a) with regard to a unit of energy input, and b) with regard to energy services, i.e., "useful work" obtained from one unit of energy input. Note that the concept of "energy services" is central to the arguments. Several scholars have pointed out that energy is not wanted for itself but for the "useful" services it can provide when consumed jointly with other equipment (cf. Berkhout et al., 2000; Binswanger, 2004; Buenstorf, 2004; Davis, 2008; Shove, 2003c).

Consider efficiency improvements in washing machines, for example. Through efficiency improvements the effective price of the particular (energy) service offered by this equipment – namely cleaning a given amount of clothes – is reduced, thus allowing for higher utilization rates at

[2] "Economy-wide effects" are also termed the "Jevons' paradox" (e.g., Polimeni and Polimeni, 2006).
[3] Taxonomies also mention "transformational effects" in consumer preferences (e.g., Greening et al., 2000; Madlener and Alcott, 2009) albeit without discussing this further.

no additional cost (leaving capital costs aside for now). In other words, more energy-using outputs, for instance, clean clothes, can be afforded, when the costs of energy services and hence the total costs of production fall with technological progress. From the perspective of neoclassical consumer theory, the actual occurrence of such rebound effects is not a surprising event (Khazzoom, 1980, p.22):

> [A]s long as the price elasticity of demand [...] is not zero, we may reasonably expect the impact of improved efficiency to be an upward pressure on demand.

In other words, a rational consumer would adjust her consumption patterns in one way or the other, as product utilization costs decrease.[4] Now, central to our argument is the conjecture by Khazzoom that the elasticity of the utilization rate with respect to the own appliance efficiency is positively correlated with the given intensity of utilization and will "approach zero as the utilization rate approaches 100%." This relationship can be represented in the form of a sigmoid curve, depicting the utilization intensity of a durable good as a function of its efficiency.[5]

The possibility of the rebound effect has triggered a debate in energy economics concerning the usefulness of the promotion of efficiency progress. Birol and Keppler (2000, p.462), for example, articulate the positive side of the rebound effect as a driver of economic growth. Other scholars raise skepticism against technological progress and "technological optimism" as such (cf. Postman, 1993; Salmon, 1977). They argue, partly without recourse to the rebound literature, that it makes much more sense to change consumer expectations concerning "normal" standards of living (e.g., Chappells and Shove, 2005; Rudin, 2000; Shove, 2003a) and that efficiency programs are a waste of resources (Rudin, 2000). Shove (2003c, p.195) even claims that consumer expectations are contingent on technological possibilities and that consumers tend to take for granted the standards of living made possible with technological advances. For the case of washing machines, this claim indeed applies (cf. section 5).

In view of this debate, it is not surprising that up to now, rebound effects have primarily been treated as an empirical question – so to assess the magnitude of the problem in the first place. In

[4] This statement would hold independent from the magnitude of the price change, for instance.

[5] When extending the single product framework to additional consumer goods, i.e., allowing for indirect rebound effects, yet further behavioral responses to an efficiency improvement in washing machines are plausible, depending on the shapes of the indifference curves. Again, indirect effects are not taken into account here.

simple terms, if it could be shown that such effects do not occur, one might come to a positive assessment of technological progress as a strategy to cope with depleting natural resources.

In this paper, it is argued, however, that a deeper theoretical analysis of the interrelation of technological change and consumer behavior is essential. Arguably, with the arguments laid out here, we make a step forward into that direction.

2.2 Empirical research

Scholarly research on rebound effects has made no attempt to extend the theoretical underpinnings of consumer behavior beyond neoclassical theory. Instead, quite a few studies from the 1980s onwards deal with an empirical assessment of the rebound effect. Estimates of the direct effect have primarily taken historical and cross-sectional data to study the price elasticity of demand to changing energy prices (e.g., Berkhout et al., 2000; Roy, 2000). The magnitudes of estimated take-back effects vary significantly, depending on the definition, i.e., the boundaries of the phenomenon studied. Polimeni and Polimeni (2006) find empirical evidence for economy-wide rebound effects. Microeconomic studies are probably more common than macroeconomic analysis. The classical example is efficiency progress regarding cars, a case for which rebound effects have been detected (e.g., de Haan et al., 2006; Greene, 1992; Khazzoom, 1980).

Few studies deal with household appliances, and if they do they usually analyze space heating or cooling systems and refrigerators, finding medium size direct effects, i.e., estimates from 10-30% for space heating, and in the range of 0-50% for cooling appliances (Greening et al., 2000; Khazzoom, 1987). We found only one study on washing machines that estimates a very small price elasticity of demand (Davis, 2008). Some scholars evaluate the magnitude of rebound effects as rather moderate anyway (e.g., Berkhout et al., 2000; Schipper and Grubb, 2000).

It has been pointed out that for an assessment of the rebound, capital costs of durable goods have to be taken into account as well (e.g., Madlener and Alcott, 2009; Sorrell and Dimitropoulos, 2008) – especially when more efficient technology is more expensive than machines with comparable product characteristics, but a lower efficiency level. More efficient washing machines, for example, seem to be more expensive than less efficient variants (Faberi, 2007). When taking into account these higher capital costs, the actual reduction in the effective price of energy services turns out to be much smaller. Estimates for the rebound effect neglecting capital costs might hence be biased in terms of overestimating the effect (Sorrell and Dimitropoulos, 2008). In contrast to

that, consumers might buy more efficient products in an anticipatory manner because they plan to use them more. In this situation, a more efficient and more expensive product is not "an obstacle" to a higher utilization rate. In other words, the higher total utilization costs do not make the occurrence of rebound effects less likely in such a case. A similar argument has been brought forth in context with time-saving appliances where households have been shown to purchase such products particularly when the family is expanding (e.g., Morgan et al., 1966).

Davis (2008) carries out a field experiment on washing machines with which to circumvent this simultaneity problem in appliance adoption. By replacing the owners' washing machines free of charge with more efficient variants, Davis can control for the simultaneity problem and extract the price effect only.[6] Davis finds that washing machines are not used more intensively when households exogenously become equipped with more efficient devices. In that case, the price sensitivity of consumers is apparently not that strong.[7]

2.3 Limitations

A few general points can be criticized about the treatment of rebound effects within a neoclassical frame of analysis. The most central issue concerns the assumptions of optimization and complete information. Optimal responses to changes in the effective price of energy services imply that the consumer can assess and calculate the energy savings resulting from technical progress – as well as the additional costs of consuming more of another good. However, "[t]he costs of energy consumption of many equipment disappear from the sight of the consumer as a part of the monthly bill. Therefore, he has no clue as to the price of energy services of equipment." (Berkhout et al., 2000) As a more realistic assumption behavioral responses might occur, but do not necessarily take place in the exact amount of freed up resources.[8]

[6] The standard approach for addressing this endogeneity issue in consumer choice is by a discrete choice model on the adoption of durable goods (Deaton and Muellbauer, 1980, ch.13). Dubin and McFadden (1984) suggested a two-step approach in which to include the utilization decision. Exactly for the endogeneity problems, Sorrell and Dimitropoulos (2008) criticize the common econometric approach to studying rebound effects and opt for the use of simultaneous equation models.

[7] Recall that the definition of the rebound effect is the price elasticity of demand, i.e., a change in efficiency followed by a change in behavior. When consumers acquire more efficient appliances in order to use them more, it is not captured by the definition of the rebound effect – an interpretation upon which the analysis by Davis (2008) draws.

[8] However, the more "intelligent" household appliances become, particularly by including feedback and sensor devices (e.g., Abrahamse et al., 2005; McCalley, 2006), the closer consumers might come to "optimal" reactions. For example, a more recent innovation in washing machines enables the device to

A further substantial shortcoming of the neoclassical framework is its narrow focus on the context between changing relative prices and changes in behavior. But correlation should not be confounded with causality. Despite a certain "co-movement" of effective prices and consumption patterns in the past, which empirical studies might detect, consumption change might truly have to be attributed to driving forces other than consumers recognizing a drop in product utilization costs. Given that the rebound effect is measured as the gap between potential and actual energy savings, it can in principle include other effects as well, which happen *in parallel* with technological advances. We therefore suggest defining rebound effects more broadly as the measurable behavioral response to technological progress for both a decline in product utilization costs as well as for other reasons.[9]

More importantly, according to Khazzoom (1980), the occurrence of rebound effects is contingent on the given utilization rate of the durable good in question. But what is the possible upper limit of the utilization rate of a given appliance? Is this merely a technical question or do other factors have to be taken into account? How to determine the gap between the present and the maximum utilization rate? Certainly, the relative utilization rate could be measured as a technical feature of the domestic appliance in question. Let, for example, the maximum utilization rate of a heating system correspond to its use at maximum temperature throughout the winter. A relative utilization rate of 50% would hence mean, for example, that the heating is switched on only every second day during winter. But such an approach is not very helpful, given that many household appliances will probably be used at levels way below their technical maximum. For example, households wash on average three to four loads of clothes per week (Ruedenauer and Griesshammer, 2004) and might not constantly use their washing machine even if this became practically free of costs.

Our central point is that the study of rebound effects would substantially gain when saturation levels of demand were taken into account, i.e., the intensity of product utilization where the own price elasticity becomes zero. Further insights into the dynamics of demand requires theoretical research into the driving forces behind changes in those saturation levels. The issue of saturation

"recognize" and "react" to suboptimal loading of the tub by sensor technologies. Washing machines then react by either using less water and energy or, alternatively, by "giving advice" for the dosage of detergent (Ruedenauer and Griesshammer, 2004, pp.18-22).

[9] Birol and Keppler (2000, p.458) would probably not subscribe to our argument as they maintain that the rebound effect concerns only price-sensitive changes in energy consumption induced by technological efficiency improvements themselves.

has been neglected in research up to now, although several scholars have emphasized its relevance (e.g., Greening et al. 2000; Madlener and Alcott, 2009). Madlener and Alcott (2009, p.374) point out nearly thirty years after Khazzoom's seminal contribution:

> Energy efficiency enables (but does not always implicate) greater energy consumption; hence our analyses must include 'the consumer'. That is, saturation or any deliberate decision to abstain from additional consumption (sufficiency strategy) does lower rebound, rendering large rebound effects […] by no means an unavoidable consequence.

Our central argument is that by taking into account saturation effects (cf. section 3), a better assessment of direction and scope of behavioral responses to the effective price change will be feasible. In section 4, we give an overview of the case study analyzed here, i.e., the consumption of cleanliness by means of electric automatic washing machines. Before turning to that issue, however, we introduce a consumption theory which can shed light on the central issues raised here. With the concepts of consumer needs and their satiation properties, the account by Witt (2001) opens up a conceptual and theoretical path towards the analysis of demand saturation. In addition to that, Witt's account deals with changes in consumer behavior for causes other than changing relative prices.

3. Insights from a needs-based account

3.1 Needs and their satiation properties as basic concepts

The consideration of saturation effects in the analysis of the rebound has been identified as one of the core issues of research (e.g., Madlener and Alcott, 2009). Already Khazzoom (1980) pointed out that the relative utilization rate of a device previous to technological improvement will affect the behavioral responses to efficiency progress. However, he did not define the central concept of the relative utilization rate further.

In order to make progress in that direction, we now turn to the theory of learning consumers by Witt (2001). Drawing upon this account, we suggest conceptualizing the phenomenon of demand saturation with the concepts of basic consumer needs and their levels of satiation. To be precise, the approach we suggest is twofold: first, the consumer needs which have driven the past development of a specific consumption activity are to be identified. In a second step, the future dynamics of these needs have to be assessed, while considering potential moments of satiation.

Witt's account differs from neoclassical consumer theory – to date the theoretical benchmark of rebound analysis – in two decisive points. First, Witt puts forth a framework which allows to systematically analyze the role of consumer motivations in changing consumption patterns. In contrast to neoclassical theory, it is the feedback between the evolution of products, on one side, and the evolution of motivations for consuming certain products, on the other, that is carefully examined in order to understand consumption growth. Second, the neoclassical analysis of rebound effects remains purely at the technological level and analyzes consumption goods in their ability to enhance the efficiency of consumption processes: according to this rationale, consumers should always appreciate and purchase more efficient energy-using products as those allow expanding product utilization at no additional cost (non-satiation assumption). Witt, on the contrary, acknowledges that consumers might be temporarily satiated with regard to certain needs in a specific consumption activity, and carefully analyzes under which conditions such satiation levels would shift.

More in general, the theory of learning consumers assumes consumer behavior to be directed toward the satisfaction of basic needs. Through their basic needs individuals are motivated to engage in consumptive activities. Need satisfaction is achieved by the consumption of specific goods and services of appropriate quality and quantity. This means that in principle for each need a specific, yet temporary, satiation level exists, which can be reached by appropriate consumption activities. In simple terms, the consumer has had "enough sleep", "enough to eat", "is warm enough", etc. Subsequent acts of consumption in that exact activity are motivated when deviations of inner physiological or psychological states from that temporary satiation level (re)occur.

The important point is that consumers are not assumed to have a priori knowledge about the suitability of consumption goods for need satisfaction. On the contrary, associations between products and the removal of deprivation states have to be learned over the course of a consumer's life. Although the need satisfaction property is in principle an objective attribute of a product, it still has to be explored by the consumer first. In addition to that, consumers develop beliefs concerning appropriate consumption levels of certain goods.

For several reasons, the need satisfaction capacity to be discovered is not an entirely subjective matter. Firstly, the common genetic basis which humans share makes some products rather than others suitable for need satisfaction, which will hold for all consumers alike. Secondly, similarities in learning processes emerge whenever consumers encounter similar sources of information –

including a certain homogenization of beliefs in intensively interacting consumer groups. And finally, the satisfaction of the need for social recognition depends upon carrying out particular, socially agreed upon forms of consumption behavior.

While levels of need satisfaction, which can be achieved by consuming a given product quantity and quality, can in principle differ between consumers despite their common genetic background (namely for different individual experiences), there exists homogeneity with respect to the need for social recognition as it is based on socially agreed upon signals or standards, implying specific consumption patterns (e.g., Bernheim, 1994). In other words, in order to receive social recognition, for example, by complying with social norms, consumers have to consume a "prescribed" product quality and quantity (cf. Woersdorfer, 2010).

Because of these regularities and objective properties of consumer behavior, the needs-based account lends itself to making some general statements about the occurrence of rebound effects.[10]

3.2 Drivers behind changing consumption patterns

Consumer exploration processes as to the need satisfying potential of consumption acts are constantly taking place, given the continuous appearance of new or qualitatively-modified products on the market. As a result, means-ends-relationships are changing, possibly altering the patterns of consumption over the long run. Witt's account identifies three major types of causes that lead to upward shifts in the consumption of specific types of goods:

(1) Consumption activities become newly associated with a not yet satiated need.

(2) By product innovation, i.e., technological change, the satiating component of a consumption activity is reduced or eliminated.

(3) The consumption level required for receiving social recognition increases as a result of social learning.

To begin with, product innovation in consumption goods might take place as a supply side strategy to increase demand through shifting the satiation potential of the product in question. As one strategy, producers try to induce a new association between a given product and additional, not yet satiated consumer needs (Witt, 2001, p.32):

[10] Naturally, the satiation level of a need itself is in most cases a non-observable theoretical construct. In contrast to that, it can be learned from surveys which motivations are related to a specific consumption act. For the case analyzed here, clothes washing, both the inputs into this consumption act in their physical form as well as the output of this consumption activity are measurable entities.

> Product innovations are brought to the market […] intended to appeal to several wants [i.e., needs; *the author*] at the same time. Products serving a combination of wants have the following property. When approaching the level of satiation the motivation to consume a direct input vanishes unless the act of consumption is simultaneously serving other, not yet satiated, innate wants. If a combination good c appeals to several wants, and if some of them are not yet satiated at a certain consumption level, or cannot so easily be satiated, a sufficient motivation for continuing to consume good c may therefore […] be maintained.

As a second strategy, the "satiating component" of a product might be reduced or eliminated by technical modification (cf. Witt, 2001). For food stuff, for example, this means reducing the calorie content of the product (Manig and Moneta, 2009; Ruprecht, 2005).

Finally, social learning can alter consumption patterns as consumption acts appealing to social recognition are intertwined with the behavior of other consumers: whenever a sufficient number of consumers and/or few but influential consumers change their behavior in socially relevant activities, other consumers will also have to modify their actions in order to further satisfy the need for social recognition. Possibly, higher consumption levels or more sophisticated forms of consumption behavior have to be demonstrated to be a socially respected person.[11] According to Witt (2001), particularly social recognition is a need that is "hard to satiate."

To sum this up, the level of consumption of a certain product at which specific consumer needs will be satisfied, can undergo changes over time. Satiation levels might shift up- as well as downwards as a consequence of product innovation and consumer learning processes. We are specifically interested in the interplay of technological evolution and changes in consumer motivations for purchasing and utilizing products.

Applying the arguments laid out here to the analysis of rebound effects, it has to be examined, firstly, which needs relate to the energy-using product in question, and secondly, what the basic satiation properties of these needs are and in how far product innovation (here: efficiency progress in washing machines) is likely to translate into consumption growth. The following hypotheses sum up these ideas:

[11] Note that satiation levels as studied here always hold for a specific consumption activity. In other words, although social motives might play a role for many more consumption acts, only the extent to which social recognition is appealed to by clean clothing will be examined here.

Hyp. (H.1): Changes in patterns of product utilization happening in parallel to technological progress need not (only) result from changes in the product's utilization costs. Instead, consumer learning processes concerning the usefulness of products might have taken place, which shifted the satiation level upwards (*Shift Hypothesis*).

Hyp. (H.2): Rebound effects as a reaction to technological change will only occur when the consumer needs addressed by this technology are not yet satiated (*Satiation Hypothesis*).

We come back to these hypotheses in section 5 when analyzing the satiation properties of the needs with which clothes washing is associated. In the following section, we provide some basic information about the case study, i.e., the market for washing machines, the evolution of cleanliness consumption over the past 150 years, and the needs associated with washing machines.

4. The case of washing machines and the consumption of cleanliness

4.1 The market for washing machines

This analysis is confined to rebound effects in context with more efficient household equipment, specifically washing machines. At present, the majority of households in industrialized countries use washing machines to ensure cleanliness. In the U.S., the diffusion degree of this device amounts to about 83%, pointing to a saturated market (EIA, 2006). In the U.K., even 92% of all households are equipped with a clothes washer (Rickards et al., 2004), while in Germany 95% of households own a washing machine (Statistisches Bundesamt, 2007). Interestingly, washing machines have been characterized as a "necessity" in U.S. consumer polls since 1972, meaning that this good has become essential to consumers (Taylor et al., 2009).

In contrast to the situation at the beginning of the 20th century, the market for washing machines at present shows a high standardization of products (Woersdorfer, 2009, ch.4). Still, some variety of washer models is available, i.e., top- and front-loaders, electric versus gas-driven washers, smaller or larger devices, etc. Countries differ in terms of the most common type of washing machine. Top-loaders, for example, are rarely purchased in Germany, while they are very common in the U.S. (EIA, 2006).

We abstract from technical characteristics of washing machines except for the degree of energy-efficiency. A labeling scheme indicating the relative efficiency of these devices has already been

introduced in the EU. By and large, more efficient clothes washers are more expensive than comparable, but less efficient machines (Mebane, 2007), but these higher investment costs are said to be paid off during the lifespan of a product (Jaffe and Stavins, 1994). With a potential of about 1840 washing cycles per machine and 3 to 4 washes per week, a washing machine will live around 10 years, at most 15 years. Despite permanent technological progress with this complex product, prices of washing machines show a downward trend (Dale et al., 2009; Ellis et al., 2007).

During the process of laundering itself, energy is used for water heating and agitating the clothes. The higher the temperature chosen, the more energy is required (Ruedenauer and Griesshammer, 2004). For washing machines, the utilization phase is attributed the major environmental impact by life-cycle assessments, i.e., neither the production phase nor the phase of waste disposal (Sammer and Wuestenhagen, 2006).

Washing machines are currently at the center of policy attention in context with EU directives on energy-using products and their labeling (*EuP Directive 2005/32/EC; Directive 92/75/ECC*). The "Eco-Design Directive" has been launched in 2005 and fosters improvements in the energy-efficiency of electrical appliances. A labeling scheme indicating the relative efficiency of these devices has already been introduced in the EU and the U.S. In recent years, a couple of market analyses and consumer surveys on laundry patterns have been initiated and financially supported by EU governments (e.g., Ruedenauer and Griesshammer, 2004; Sammer and Wuestenhagen, 2006; SIFO, 2003). In view of the energy requirements of clothes washing and the widespread diffusion of these devices as well as the policy objective of energy savings, it is not surprising that public policies regulate this consumption activity. However, the promotion of efficiency improvements in washing machines need not be an effective policy. With these devices becoming more energy-efficient, consumers might use them more intensively, thus producing rebound effects which lower the energy savings made feasible by technological progress.

In the following section, we present a stylized overview of the evolution of cleanliness consumption over the past century, highlighting the basic trends of technological progress and utilization patterns of washing machines. The description and interpretation of past consumption trends is shown to be an important element of the analysis of rebound effects as it provides a basic understanding of this specific consumption activity.

4.2 The past evolution of technological progress and washing machine utilization

The technological means of doing the laundry have been substantially transformed over the past 150 years (cf. Giedion, 1948; Hardyment, 1988; Strasser, 2000[1982]). At the beginning of the 20th century, only 8% of U.S. families possessed a washing machine, while practically all households had to deal with scrubboards and tubs, which made clothes washing a highly detested, time and labor consuming task (e.g., Cowan, 1983; Giedion, 1948; Hardyment, 1988). Given that hardly any tools were available for doing the laundry back then but a simple washboard and home-made soap, and given that all water had to be carried into and out of the house, it is no surprise to learn that clean clothes were not paid much attention to by the majority of consumers. In fact, consumers possessed few clothes and changed them only regularly for the Sunday visit to the church (Strasser, 2000[1982], p.106). At the same time, there were also wealthy middle-class households who outperformed the majority of consumers in terms of financial resources and cleanliness of appearance (Ashenburg, 2007, p.169). These levels of cleanliness however were not the result of their own labor: instead, well-to-do households usually outsourced this task to domestic servants or washerwomen.

Over the course of time, laundry equipment became more advanced, going through four distinct phases of technological progress, namely "Blue Monday" (19th century), mechanization (end of 19th century), electrification (around 1915) and automation (around 1940) (cf. Woersdorfer, 2009, ch.4). At present, four out of five U.S. households own an electric, automatic washing machine (EIA, 2006, p.52), which, in comparison to the 19th century conditions, made not only time savings, but more importantly, substantial reductions in physical effort feasible ("drudgery"). Hence, laundry washing can no longer be called a "backbreaking labor" today (Buehr, 1965, p.61). While 19th century consumers did face a trade-off between wanting clean clothes on one side but having to take into account drudgery on the other, no such trade-off exists at present.

With the proliferation of time- and labor saving washing machines during the 20th century, the households' levels of cleanliness have changed substantially, i.e., consumers have increased the amount of clothes washed (e.g., Cowan, 1983; Klepp, 2003; Shove, 2003a; Silberzahn-Jandt, 1991; Strasser, 2000[1982]). Already with the advent of the electricity-driven washing machine in the 1920s, clothes were changed more often (Hewes, 1930; Strasser, 2000[1982], p.268; Wilson, 1929) – a trend that has continued for quite some time in the 20th century. U.S. consumers nowadays wash about three times the amount that was common in the 1950s (Shove, 2003b). For the year

2000, the average German household washes about 525 kg of clothes p.a., which is about double the laundry quantity of 1960 (277 kg) (Ruedenauer and Griesshammer, 2004, p.38). These increasing laundry amounts are reflected in a significant growth in the consumption of soap and detergents in the United States as well as Europe (cf. table 1 and table 2).

Table 1: Soap and detergent sales in the U.S. in 1000 tons

	Soap	Synthetic detergents
1940	1410	4.5
1950	1340	655
1960	583	1645
1972	587	4448

Source: http://www.chemistry.co.nz/deterghistorypart3.htm (retrieved 12.12.2009).

Table 2: Per capita consumption of soaps, detergents and cleaning compounds

	1960	1970	1980
West Europe	9.7	13.8	18.9
North America	12.8	20.2	30.1
World	3.8	4.6	6.3

NOTES: kg per capita. Source: Henkel Survey (1984).

That the mechanization of the home went hand in hand with rising household standards is by now a commonplace in the sociological literature (e.g., Fine, 1999; Robinson, 1980; Schor, 1991, p.89; Strasser, 2000[1982]). In addition, consumers nowadays display fairly similar standards of cleanliness. Cowan (1983) maintains that without technical progress in laundry equipment the current levels of cleanliness would have been out of reach.[12] Also the assimilation of cleanliness standards between the two consumer groups was contingent upon technical progress: not only did less well-to-do consumers lack the financial means to pay servants for their support in

[12] It was by the influential book by Ruth Schwartz Cowan (1983) that the increase in "household standards" more in general, including standards of cleanliness, has been brought to attention. The observation that despite the big leaps in technical advances women are still doing so much housework has been referred to as the "Cowan paradox" (Mokyr, 2000).

housekeeping; even with growing income, there would not have been sufficient human labor (i.e., workers) to achieve these standards.

This past co-development of technological progress in washing machines and rising laundry quantities can be referred to as a rebound effect when interpreting the time and labor savings made feasible with technological progress as a reduction in the relative utilization costs of washing machines (or as a decline in the shadow price of clean clothes).[13] In view of this interpretation, the promotion of efficiency progress in washing machines might not be an adequate policy tool for actually achieving energy savings.

However, this perspective neglects an important point. Although technological progress reducing the input of time and labor into the domestic production of cleanliness was a necessary condition for making feasible the current standards of cleanliness, it still has to be explained why consumers also wanted to increase the levels of cleanliness. The arguments laid out so far leave aside this very central issue as they do not contain any reference as to the consumer motivations for carrying out specific consumption activities in the first place.

We argue that an improved understanding of the historical processes and the future occurrence of rebound effects is achieved when taking into account the consumer motivations underlying cleanliness consumption as such. The next section introduces these motivations and shows that in the past, conditions favorable to growing laundry quantities have existed such that technological advances led to rising utilization patterns.[14]

[13] In fact, for this phenomenon, a proper concept has been coined: changes in the utilization of a product as a result of time-saving innovations in that exact product are referred to as the "rebound effect with respect to time." (Binswanger, 2004; Jalas, 2002)

[14] Note that we leave aside sociological explanations here such as gender roles and the like, as this analysis is confined to the neoclassical theory and the needs-based account, respectively. Also in the sociological literature, one finds mechanistic explanations for the rising household standards such as rising cleanliness standards (e.g., Robinson, 1980). In simple terms, when the housewife is at home "anyway", and when the adoption of a time-saving product reduces the time that is needed for carrying out a certain task, the housewife might simply produce more commodities in the exact same time. There also exist less mechanistic explanations, which point to gender roles and fairness of division of labor between the homemaker and the spouse (Bianchi et al., 2000; Cowan, 1976; Fox, 1990; Robinson and Milkie, 1998; Vanek, 1978).

5. Why rebound effects have occurred in the past, but are not likely in the future

5.1 Present consumer motivations for clothes washing

The utilization intensity of washing machines is contingent upon the needs appealed to by the utilization of this product. As a more recent consumer survey (SIFO, 2003) indicates, two basic needs are nowadays associated with clean clothes: health and social recognition. In the medical field, it is common knowledge that the washing of textiles can contribute to hygiene via disinfection. Effectiveness, however, depends upon the type of textiles and laundering practices: higher temperatures and ample rinsing of clothes substantially reduces the number of microorganisms (Nichols, 1970; Sattar et al., 1999; Terpstra, 1998). According to the survey, social motives are equally relevant. Concerning the question how much they agree (on a five-point scale) with the statement that "it is embarrassing to wear clothes with a body odour," a large share of respondents in several European countries "fully agreed." (Greece: 80%; Netherlands: 80%; Norway: 74%; Spain: 95%) This quote illustrates that consumers nowadays expect of one another to be clean. In addition, there appears to exist a mutual understanding of what cleanliness means – namely the absence of body odor, as can be ensured by clothes washing.

In concrete terms, we thus assume the activity of clothes washing to be directed towards the satisfaction of the basic needs for health and social recognition, which are stable elements in consumer behavior, accounting for a structural component in laundry washing. Drawing upon Witt (2001), we further assume that at a given point in time a temporary satiation level of these consumer needs exists – as appealed to by the activity of clothes washing. Note that what is considered appropriate cleanliness from the perspective of society, i.e., the social standard of cleanliness, need not correspond with the level actually necessary to meet health concerns from an objective perspective (see below).[15]

The extent to which these motivations become manifest in consumer behavior, however, might undergo changes over time. In fact, we assume the significance of these needs in terms of influencing laundry patterns to be contingent upon historical and regional circumstances. The consumer's awareness as to the hygienic effects of clean clothing might undergo changes over time

[15] Note that the activity of laundry washing is not contingent upon actual states of deprivation occurring. Consumers do not wait until being ill or until others let them know their disapproval with their appearance, but rather act in an anticipatory manner. By this anticipatory behavior, consumers reinforce certain "normal" patterns of behavior in society.

as well as the relevant peer-group standard of cleanliness. Tracing back the evolution of the demand for cleanliness to these innate motives we thus have to control for the systematic changes in the importance of these motivations in form of a rising hygienic awareness and changing social normative expectations. As necessary conditions for changes in the social standard to affect consumer behavior, the changes must be either observable and/or consumers obtain information as to changes in the standard.

5.2 Satiation of needs in the evolution of cleanliness consumption

In what follows, we discuss in turn each of the needs that have been associated with cleanliness consumption over the past 150 years. We will shortly explain, which effects these needs unfolded on cleanliness consumption in the past and which further dynamics are to be expected in the future. That way, we illustrate how changes in cleanliness consumption happening in parallel to progress in technology can be traced back to *consumer motivations* (cf. the *Shift Hypothesis*). This short discussion shall also yield an understanding in how far the needs related to clothes washing have already been satiated or if further increases in cleanliness consumption are to be expected in the future – thus potentially triggering rebound effects.

The consumer survey by SIFO (2003) indicates which needs consumers currently associate with the activity of clothes washing, namely social recognition and health as pertaining to the cleanliness of clothes. In the 19th century, the then prevailing technique of laundry washing with only the simplest equipment and the accompanying physical strain has brought yet another need into play: the need to avoid painful physical effort. With technological development, the trade-off between clean clothes on one side and drudgery avoidance on the other has been eliminated, however (cf. Woersdorfer, 2009, ch.4). In other words, consumers learned to associate the use of washing machines with drudgery-avoidance.

Analogously to condition (2), the factor that inhibits the consumption of cleanliness has been eliminated by technological progress; and while the drudgery that was involved in clothes washing clearly held cleanliness levels low for the majority of consumers who could not outsource this task, no such limitating factor exists at present. From this perspective, a further upward tendency in consumption is generally feasible. However, the drudgery avoidance disposition alone would not go in favor of a higher utilization rate – and thus potentially in favor of the rebound effect. For the highest reasonable level of drudgery avoidance is already achieved (only by not washing clothes at

all, yet more physical effort could be saved). In that regard, the absolute level of satiation with regard to that need has already been reached, and a further upward pressure is not to be expected.

A second need linked to cleanliness consumption is that of consumer health. Elsewhere we have shown that the connection between cleanliness of clothes and the avoidance of illness emerged in the 19th century as a consequence of an enhanced understanding of the causes and transmission channels of infectious diseases (Woersdorfer, 2010). This new scientific knowledge became known to the public via social-cognitive learning processes, i.e., the educational campaigns by social reformers and home economists, starting around the end of the 19th century. With the need for health, we see yet a further factor for consumption growth fulfilled, as derived from the theory of learning consumers, namely that learning processes bring about new understandings concerning the relationship between consumption activities on one side and consumer needs on the other. Put differently, cleanliness consumption increased when this consumption activity became associated with an additional need (condition (1)). Given that cleanliness consumption has increased in the course of this social learning process, an upward tendency in cleanliness consumption as a result of new health knowledge might be possible. However, recent debates in the medical sciences rather point to the fact that current cleanliness levels might actually be too high and not too low from the perspective of consumer health (Hannuksela and Hannuksela, 1996; Matthies, 2003). The current scientific debate thus does not go in favor of a further increase in consumption levels.

Finally, current patterns of cleanliness consumption are linked to the need for social recognition, i.e., to a social norm of cleanliness, to be precise. The social norm has its origin in the historical context of mid 19th century, when scientific knowledge on the causes of infectious diseases progressed substantially (cf. Woersdorfer, 2010).[16] The social standard was contingent upon changes in health information and might thus also change in the future with changes in the beliefs of how clothes washing and health are intertwined. As we have just argued, from the perspective of scientific knowledge, an upward shift in cleanliness is not to be expected such that the social norm, if it is still connected to the cleanliness level justified from a hygienic perspective, should not show further upward tendencies.

Note the interdependencies between the basic needs associated with clothes washing and cleanliness: the social norm has its origin in the context of the Hygienic Movement of the 19th

[16] To be precise, the rising cleanliness standard demanded of all consumers to be clean according to an understanding of cleanliness which clearly exceeded the cleanliness levels of the majority of the population.

century, but it unfolded its strong impact on consumption patterns only when technological progress in washing machines made this feasible by reducing the drudgery component in this activity. Two historical processes are thus intimately linked: on the one hand, technical advances in clothes washers eliminated the tendency of households to avoid the task of laundry washing. On the other, consumers also had an interest to make use of this improved technology when the social norm of cleanliness came into being (cf. the *Shift Hypothesis*).

However, not necessarily does the social norm of cleanliness show such an intimate connection to the hygienic standard any longer. When leaving aside the interactions between the social and the hygienic standard, there is still room for changes in the social standard stemming from the social significance of this particular consumption activity itself. Social recognition is always defined in relation to the behavior of others so that changes in the behavior of others induce the consumer to adjust her consumption patterns as well (condition (3)).

In fact, cleanliness has been said to represent a socio-cultural construct (Douglas, 1984; Shove, 2003a), i.e., a concept "laden with cultural significance and meaning" (Shove, 2003b, p.195). When clothes are considered "clean", in terms of meeting social requirements, is not self-explaining and hence deserves a definition that is moreover socially shared and agreed upon.[17] In other words, social constructs are historically and technologically shaped evolved beliefs and expectations (Chappells and Shove, 2005). The socially-contingent standards of cleanliness can thus differ from and will most likely exceed the hygienic standard, for consumption activities which are relevant for the social standing of a person have an immanent tendency to increase. The need for health, in turn, represents the minimum level of cleanliness consumption as the physiological origin.

Can we also define an upper limit for the social standard of cleanliness? We find it plausible to assume social standards not to exceed that level of consumption, beyond which additional consumption cannot be demonstrated towards others. We refer to this as the "boundary of visibility" in social standards. Such a boundary can be expected to hold for the case of cleanliness consumption via clothes washing: beyond a certain cleanliness level, consumers cannot differentiate between different levels of cleanliness – neither in terms of smell nor vision. We assume that consumers would not want to exceed the consumption level which corresponds to the

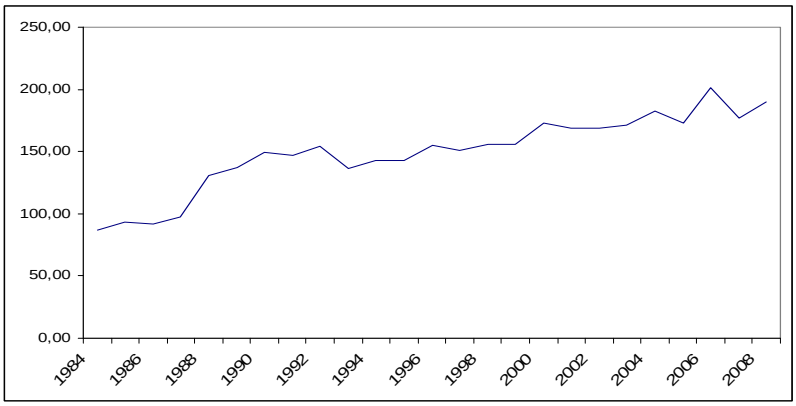
[17] The malleability of the understanding (definition) of cleanliness with historical course of time has been demonstrated (e.g., Cowan, 1983; Tomes, 1998; Vigarello, 1998).

boundary of visibility as this will not be granted social recognition. To the extent to which social recognition depends on a standard of cleanliness that can be sensed, a satiation point has been reached here.

5.3 Recent figures on cleanliness consumption

Can we find indicators that current laundry practices have reached the boundary of visibility, which would let us expect that further increases in efficiency will not lead to rebound effects? Although it is not possible to get direct evidence for a boundary of visibility, some indirect evidence can be found. Firstly, the laundry amounts that German consumers handle today have almost stagnated from 1990 to 2000 (Ruedenauer and Griesshammer, 2004, p.38). In the year 2000, German households wash on average 525 kg of clothes per annum compared to 503 kg per annum in 1990 and only 277 kg in 1970. Secondly, the time U.S. households spend doing the laundry ("clothes maintenance") has been rather constant since the 1970s, i.e., between 1970 and 2003 (Egerton et al., 2006, p.58). Finally, more recent figures from the U.S. Consumer Expenditure Survey also show that expenditures on laundry and cleaning supplies have been rather constant (cf. figure 1).

Fig. 1: Laundry and cleaning supplies



NOTES: Average annual expenditures in U.S. dollar (Consumer Expenditure Survey). Source: Author's compilation from Bureau of Labor Statistics (cf. *http://www.bls.gov/cex/csxstnd.htm*).

These findings might be interpreted as indicators that the boundary of visibility has already been reached, i.e., that consumers do not produce higher cleanliness levels because they can no longer

demonstrate this to other consumers. However, in order to sufficiently substantiate our claim, more empirical evidence will have to be gathered in the future.

To sum up, technological progress and consumer learning processes have been closely intertwined in the past and produced a growth in laundry quantities that appears to have come to a halt now, for the needs involved in clothes washing have reached their level of satiation (cf. the *Satiation Hypothesis*).

6. Conclusions

In this paper, we discussed the occurrence of rebound effects with regard to more energy-efficient washing machines from a theoretical perspective. While we scrutinized the neoclassical explanation also, the goal was to demonstrate that additional insights into the phenomenon of rebound effects will depend upon widening the theoretical basis beyond neoclassical accounts. More precisely, the paper demonstrates how the analysis would benefit from taking into account the consumer motivations underlying changing consumption patterns. In our view, the rebound effect to energy efficiency progress is only a special case of the more general phenomenon that product utilization patterns evolve with technological progress.

It was shown how the present residential patterns of laundry washing reflect consumers' past learning processes in terms of linking clean clothes to the consumer needs for health and social recognition, and associating washing machines with a decline in drudgery. Although further improvements in washing machines in terms of energy-efficiency do imply a reduction in utilization costs of washing machines, the consumers' reaction to technological progress will depend on the satiation properties of the underlying needs. We found that a further upward tendency in cleanliness consumption was not to be expected such that rebound effects to technological progress are unlikely, at least from the perspective of the basic needs involved in clothes washing.

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